

US007042331B2

(12) **United States Patent**
Zhou et al.

(10) **Patent No.:** **US 7,042,331 B2**
(45) **Date of Patent:** **May 9, 2006**

(54) **FABRICATION OF THICK FILM ELECTRICAL COMPONENTS**

(75) Inventors: **Jiming Zhou**, Kokomo, IN (US);
Dwadasi H. Sarma, Kokomo, IN (US);
Carl W. Berlin, West Lafayette, IN (US);
John D Myers, Kokomo, IN (US);
M. Ray Fairchild, Kokomo, IN (US)

(73) Assignee: **Delphi Technologies, Inc.**, Troy, MI (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 150 days.

(21) Appl. No.: **10/639,794**

(22) Filed: **Aug. 12, 2003**

(65) **Prior Publication Data**
US 2005/0035845 A1 Feb. 17, 2005

(51) **Int. Cl.**
H01C 1/14 (2006.01)

(52) **U.S. Cl.** **338/328**; 338/309

(58) **Field of Classification Search** 338/51,
338/52, 239, 252, 254, 260, 307, 309, 320,
338/308, 306, 332, 314

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,370,262 A * 2/1968 Marty et al. 338/309

4,613,844 A *	9/1986	Kent et al.	338/314
4,766,412 A *	8/1988	Takakura et al.	338/334
4,901,052 A	2/1990	Chapel, Jr. et al.	
5,256,836 A	10/1993	Ezaki	
5,548,268 A	8/1996	Collins	
5,683,606 A	11/1997	Ushikoshi et al.	
5,990,780 A *	11/1999	Caddock, Jr.	338/309
6,136,512 A	10/2000	Doeling	
6,229,098 B1 *	5/2001	Dunn et al.	
6,429,533 B1 *	8/2002	Li et al.	338/22 R
6,507,993 B1 *	1/2003	Dunn	338/309

OTHER PUBLICATIONS

Copy of PCT search report dated Aug. 3, 2005.

* cited by examiner

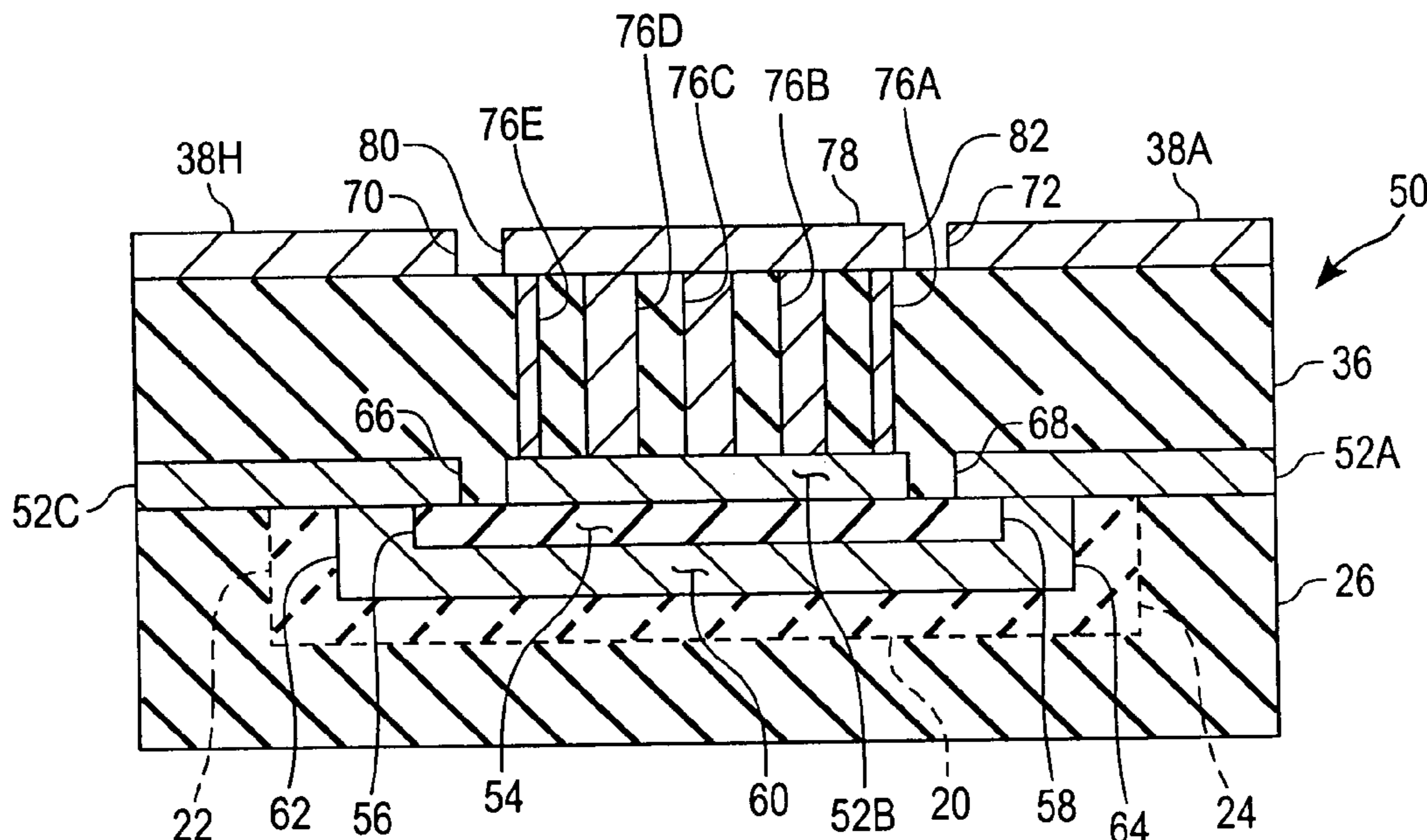
Primary Examiner—Tu Hoang

(74) Attorney, Agent, or Firm—Scott A. McBain

(57) **ABSTRACT**

A thick-film resistor component may include a thick film component formed between a thick-film resistor and an electrically conductive sheet, wherein a portion of the sheet is selectively removed to form resistor contacts while exposing a portion of the thick-film component. Electrical terminals to a thick-film resistor may be sized to reduce stress and/or be selectively positioned relative to the resistor to define a desired resistor value. A thick-film resistor may include one or more resistor segments configured to be selectively open-circuited to incrementally adjust the value of the resistor.

15 Claims, 4 Drawing Sheets



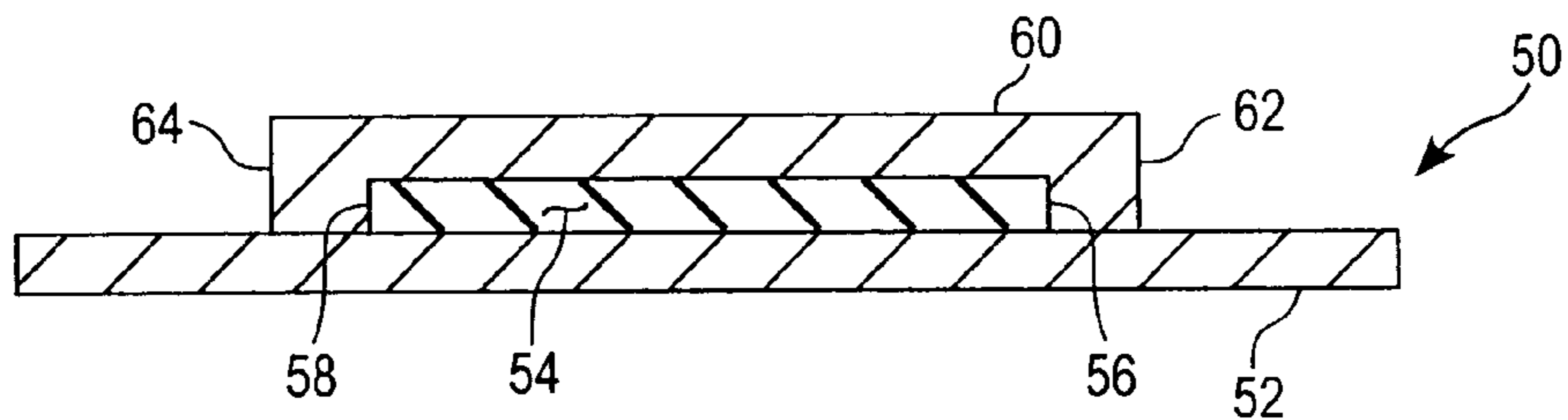


FIG. 1A

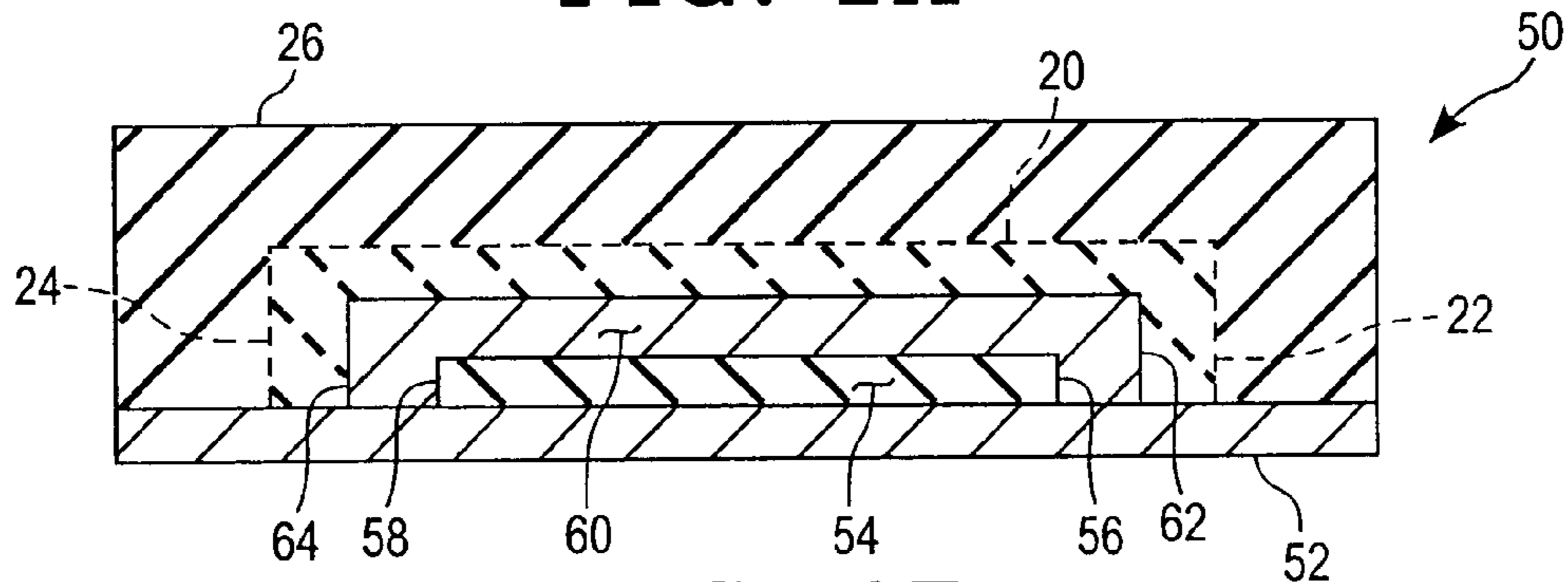


FIG. 1B

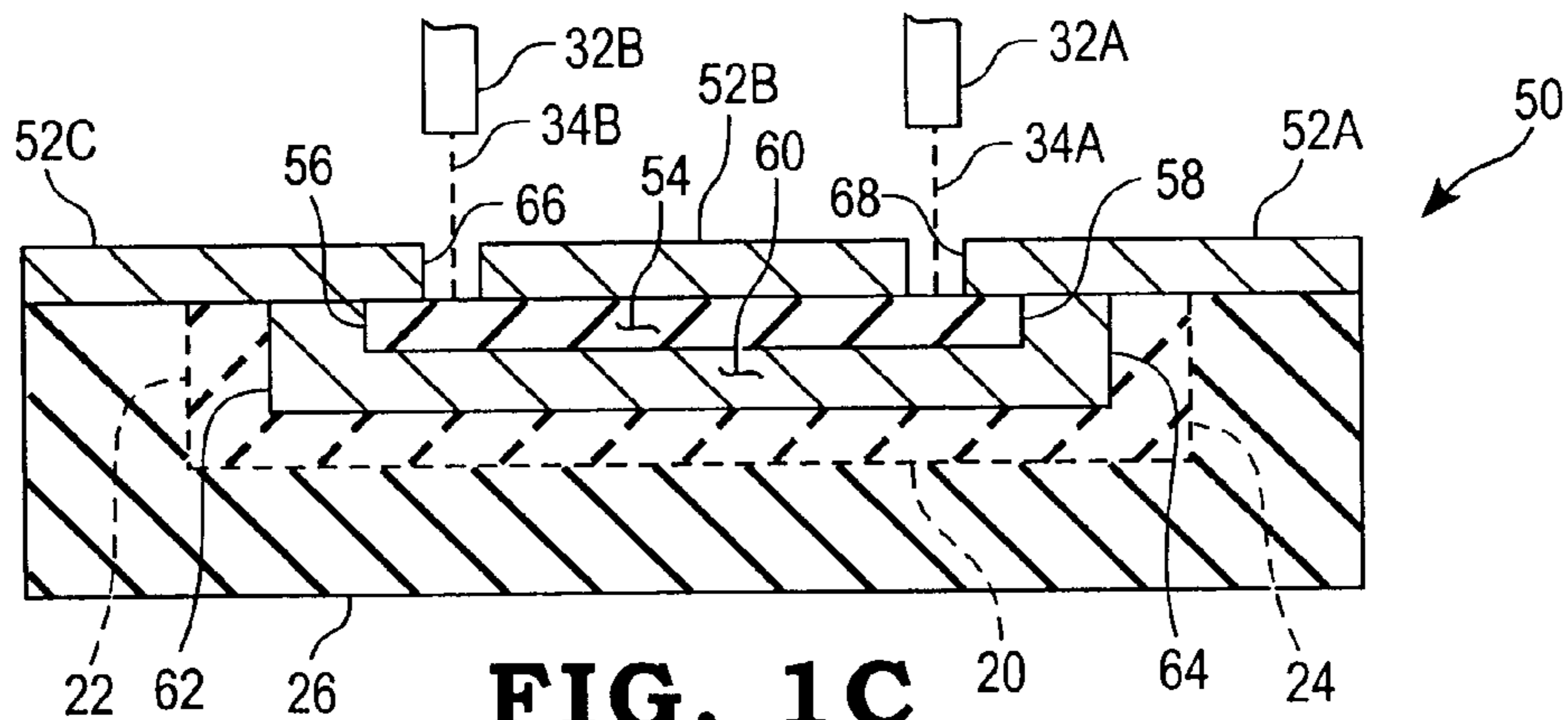


FIG. 1C

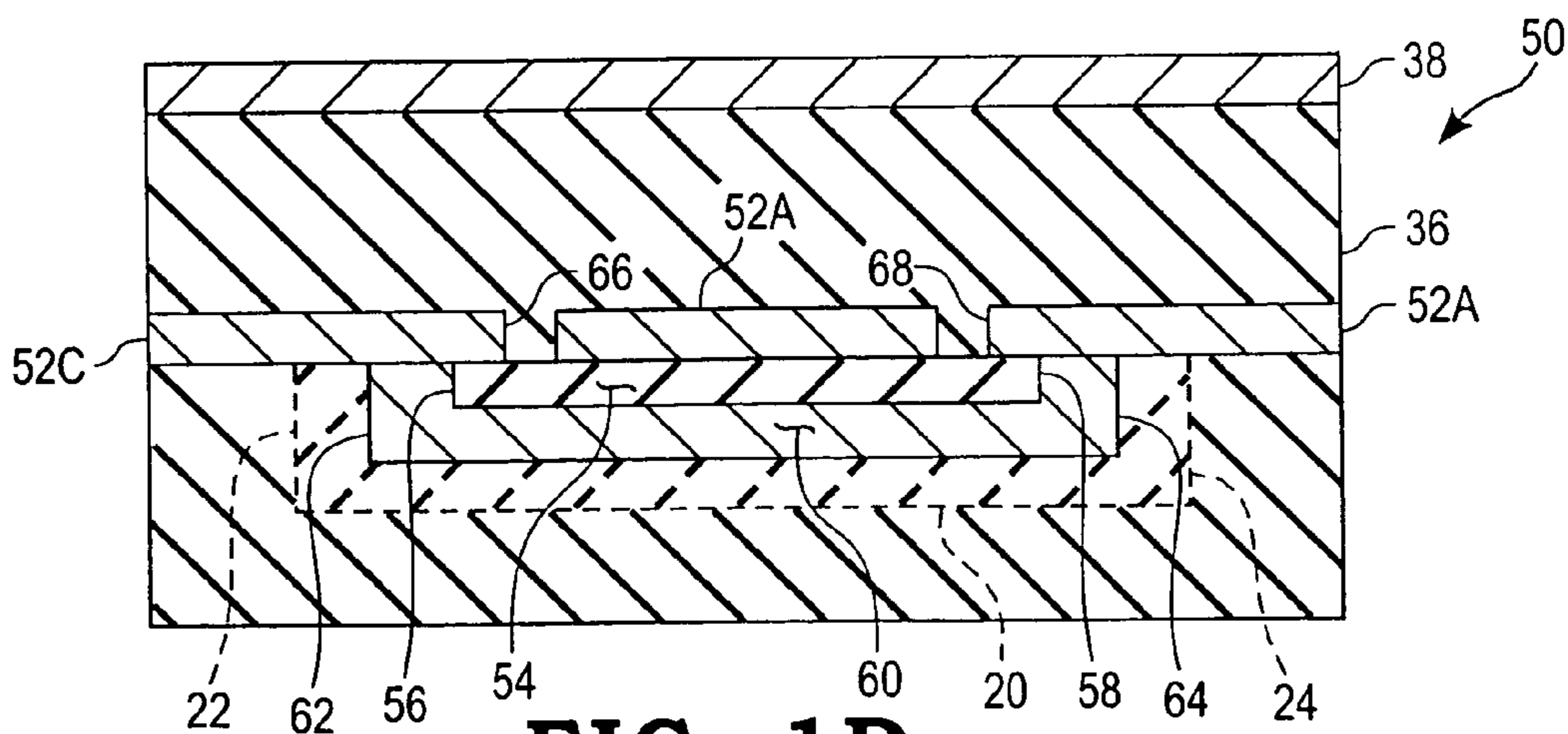


FIG. 1D

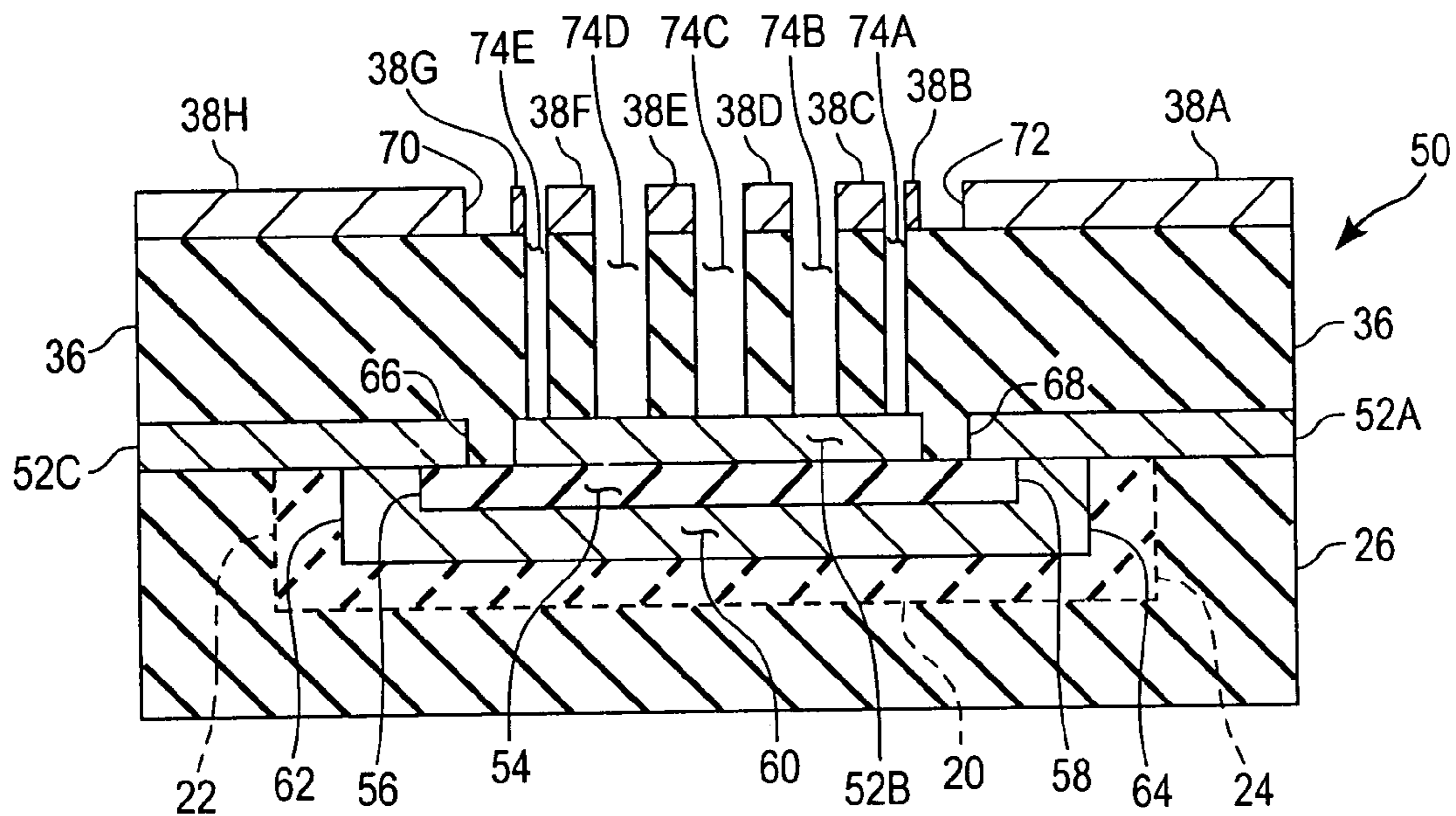


FIG. 1E

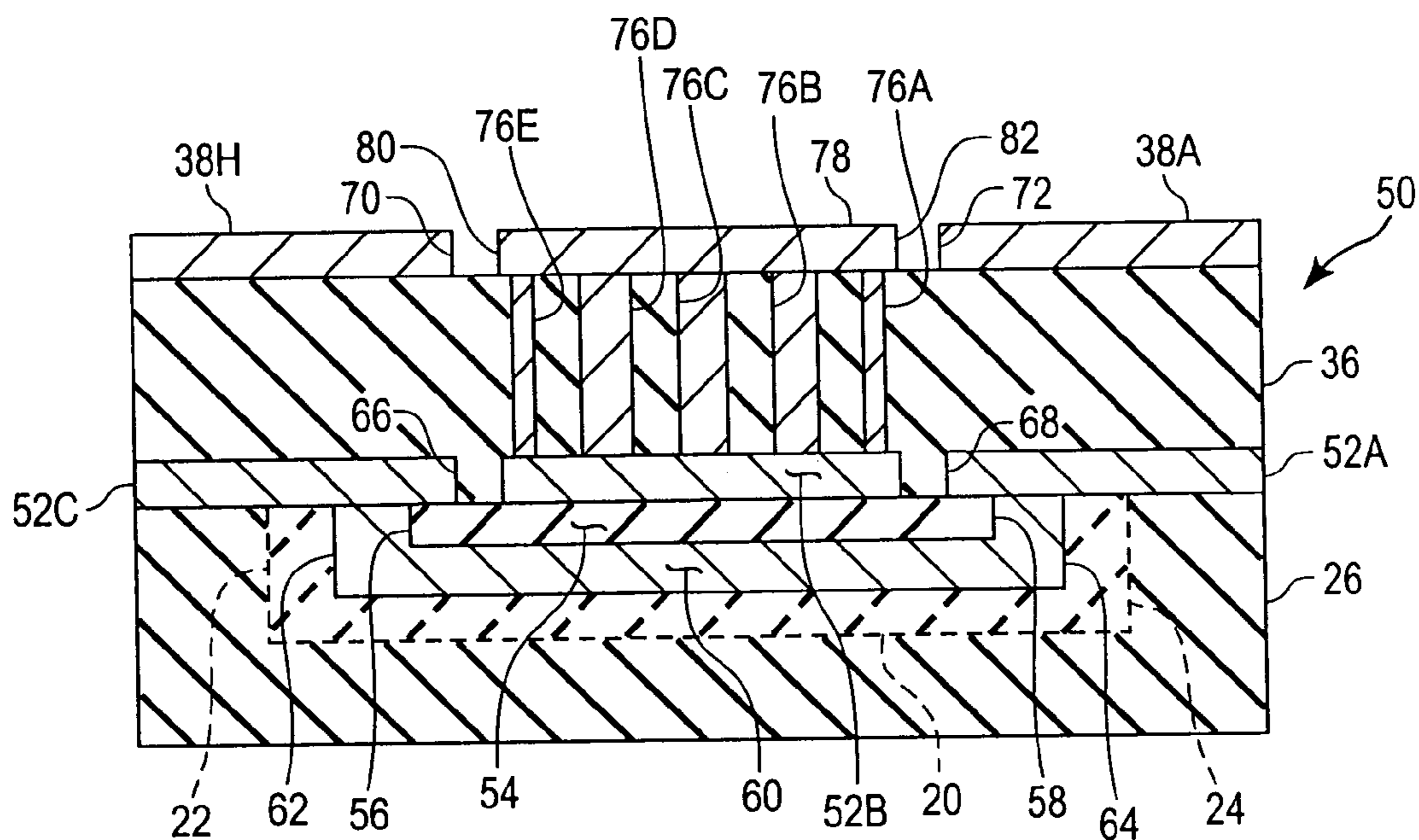


FIG. 1F

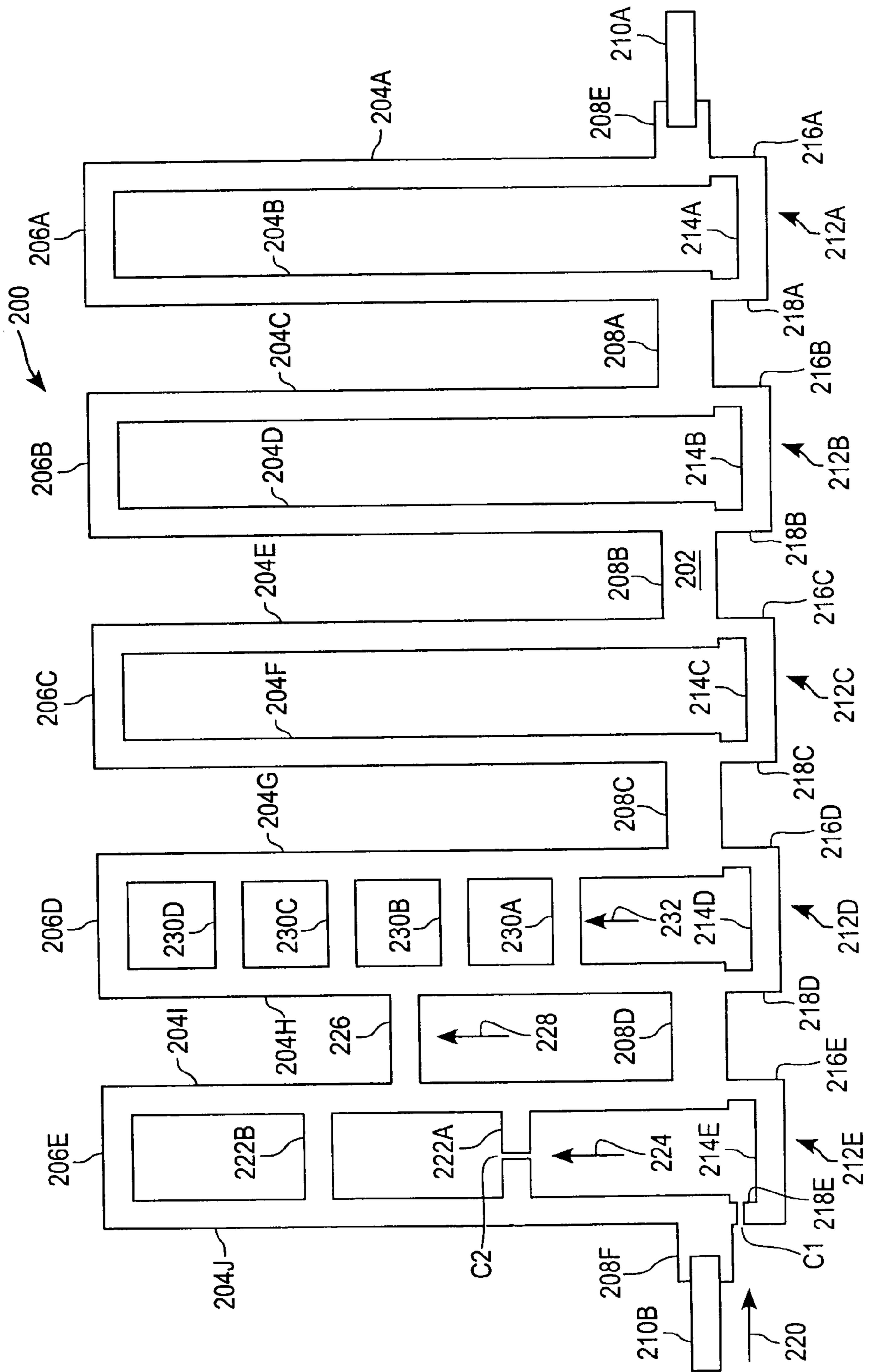


FIG. 3

FABRICATION OF THICK FILM ELECTRICAL COMPONENTS

TECHNICAL FIELD

The present invention relates generally to materials and techniques for fabricating thick film resistor elements, and more specifically to such materials and techniques for improving thick film resistor fabrication, trimmability, mechanical stability, thermal matching between resistor and terminal elements and other thick film resistor properties and features.

BACKGROUND OF THE INVENTION

It is generally desirable to fabricate thick-film resistor components on flexible and non-flexible substrates for the purpose of providing discrete resistor components. It is further desirable to improve the fabrication, trimmability, mechanical stability, thermal matching between resistor and terminal elements, and other thick film resistor properties and features.

SUMMARY OF THE INVENTION

The present invention comprises one or more of the following features or combinations thereof. A thick-film resistor component may comprise a first electrically conductive sheet having first and second opposite surfaces, a first thick-film component having first and second opposite surfaces, the first surface of the first thick-film component adhered to the first surface of the first sheet, and a first thick-film resistor having first and second surfaces, the first surface of the first resistor adhered to the second surface of the first thick-film component and to the first surface of the first sheet adjacent to the first thick-film component. A first electrically insulating layer may be formed over the combination of the first thick-film component and the first resistors and the first electrically conductive sheet. A portion of the first sheet may be selectively removed adjacent to the first thick-film component such that a remaining first portion of the first sheet defines a first electrical contact to the first resistor, a remaining second portion of the first sheet defines a second electrical contact to the first resistor, and the first surface of the first thick-film component is at least partially exposed therebetween, the first resistor forming the thick-film resistor component between the first and second contacts.

The portion of the first electrically conductive sheet may be selectively removed via an etchant, and the first thick-film component may be formed of a material that is unreactive with the etchant and the first thick-film resistor may be formed of a material that is reactive with the etchant, the first thick-film component shielding the first thick-film resistor from the etchant.

The first thick-film component may be formed of an electrically insulating material such as, for example, SiO₂. Alternatively, the first thick-film component may be a second thick-film resistor, wherein the second surface of the second thick-film resistor is electrically bonded to the first surface of the first resistor, and wherein the first and second contacts are each in electrical contact with both of the first and second thick-film resistors, the first and second thick-film resistors defining a parallel-connected thick-film resistor component.

The material forming the first thick-film resistor may have a higher metal content than the material forming the second thick-film resistor.

The first thick-film resistor may be a low-valued sense resistor and the second thick-film resistor may have a resistor value substantially higher than the low-valued sense resistor.

5 The first thick-film resistor may be formed of a combination of a metallic compound and an electrically insulating material and the second thick-film resistor may be formed of a polymer-based resistor film.

10 The resistor component may further include an electrically insulating film formed over the second surface of the first thick-film resistor and in contact with the first surface of the first sheet about a periphery of the combination of the first thick-film component and first thick-film resistor. The resistor component may further include a second electrically conductive sheet formed over the second electrically insulating layer.

15 The resistor component may further include a number of thermally conductive members extending through the second electrically insulating layer in contact with a remaining third portion of the first electrically conductive sheet in contact with the first thick-film component and positioned between the first and second electrical contacts. A thermally conductive sheet may further be formed on the second electrically insulating layer in electrical contact with the number of thermally conductive members and electrically isolated from the second electrically conductive layer, the third portion of the first electrically conductive sheet, the number of thermally conductive members and the thermally conductive sheet forming a heat sink for the thick-film resistor component.

20 A method for fabricating a thick-film resistor component may comprise the steps of patterning a thick-film resistive material on a substrate, forming a first conductor having a terminal portion extending into the resistive material along a first edge thereof, forming a second conductor having a terminal portion extending into the resistive material along a second edge thereof, and positioning the terminal portions of the first and second conductors relative to the resistive material to define a desired resistance value of the thick-film resistor component therebetween.

25 The step of forming a first conductor may include forming the first conductor with the terminal portion thereof extending into the resistive material along the first edge thereof and terminating at a second edge thereof, and the step of forming a second conductor may include forming the second conductor with the terminal portion thereof extending into the resistive material along the third edge thereof and terminating at a fourth edge thereof. The first edge of the resistive material may be the same as the second edge thereof, and the third edge of the resistive material may be the same as the fourth edge thereof.

30 The step of forming a first conductor may include forming the first conductor with the terminal portion thereof extending into the resistive material along the first edge thereof and exiting the resistive material along a second edge thereof. The step of forming a second conductor may include forming the second conductor with the terminal portion thereof extending into the resistive material along the third edge thereof and exiting the resistive material along a fourth edge thereof. The first edge of the resistive material may be the same as the second edge thereof, and the third edge of the resistive material may be the same as the fourth edge thereof.

35 The first edge of the resistive material may be opposite the second edge, and the third edge of the resistive material may be opposite the fourth edge, the first and second edges each adjacent to the third and fourth edges.

The thick-film resistor material may be formed of a resistive ceramic material, and the method may further include the step of sizing the terminal portions of the first and second conductors to minimize stress resulting from a mismatch between a coefficient of thermal expansion of the thick-film resistor material and a coefficient of thermal expansion of the terminal portions of the first and second conductors.

A thick-film resistor component may comprise a thick-film resistor material formed on a substrate in a serpentine configuration with a plurality of long legs having long edges positioned adjacent to each other and a plurality of short legs connecting alternate ends of the plurality of long legs together such that resulting adjacent pairs of the plurality of long legs each have a closed end and an open end. A first resistor segment may be formed on the substrate from the thick-film resistor material and connect together an adjacent pair of the plurality of long legs at a corresponding open end thereof. The first resistor segment may be configured to be selectively open-circuited to incrementally adjust a resistance value of the thick-film resistor component. The resistor component may further include a plurality of the first resistor segments each formed on the substrate from the thick-film resistor material and connecting together different ones of the adjacent pairs of the plurality of long legs at corresponding open ends thereof, and each of the plurality of the first resistor segments may be configured to be selectively open-circuited to incrementally adjust the resistance value of the thick-film resistor component.

The resistor component may further include a second resistor segment formed on the substrate from the thick-film resistor material and connecting together an adjacent pair of the plurality of long legs along the long edges and between the open and closed end thereof. The second resistor segment may be configured to be selectively open-circuited to incrementally adjust the resistance value of the thick-film resistor component. The resistor component may further include a plurality of the second resistor segments each formed on the substrate from the thick-film resistor material and connecting together selected ones of adjacent pairs of the plurality of long legs along the long edges and between the open and closed ends thereof, and each of the plurality of the second resistor segments configured to be selectively open-circuited to incrementally adjust the resistance value of the thick-film resistor component.

The resistor component may further include a first conductor having a terminal portion extending into an open end of a first one of the plurality of long legs, and a second conductor having a terminal portion extending into an open end of another one of the plurality of long legs, the thick-film resistor component defining the resistance value between the terminal portions of the first and second conductors.

A thick-film resistor component may comprise a thick-film resistor material formed on a substrate in a serpentine configuration with a plurality of long legs having long edges positioned adjacent to each other and a plurality of short legs connecting alternate ends of the plurality of long legs together such that resulting adjacent pairs of the plurality of long legs each have a closed end and an open end. A first resistor segment may be formed on the substrate from the thick-film resistor material and connect together an adjacent pair of the plurality of long legs along their long edges between a corresponding open and closed end thereof. The first resistor segment may be configured to be selectively open-circuited to incrementally adjust a resistance value of the thick-film resistor component. The resistor component may further include a plurality of the first resistor segments

each formed on the substrate from the thick-film resistor material and connecting together selected ones of the adjacent pairs of the plurality of long legs along their long edges between open and closed ends thereof, and each of the plurality of the first resistor segments configured to be selectively open-circuited to incrementally adjust the resistance value of the thick-film resistor component.

The resistor component may further include a second resistor segment formed on the substrate from the thick-film resistor material and connecting together an adjacent pair of the plurality of long legs at an open end thereof. The second resistor segment may be configured to be selectively open-circuited to incrementally adjust the resistance value of the thick-film resistor component. The resistor component may further include a plurality of the second resistor segments each formed on the substrate from the thick-film resistor material and connecting together different ones of adjacent pairs of the plurality of long legs at corresponding open ends thereof, and each of the plurality of the second resistor segments configured to be selectively open-circuited to incrementally adjust the resistance value of the thick-film resistor component.

The resistor component may further include a first conductor having a terminal portion extending into an open end of a first one of the plurality of long legs, and a second conductor having a terminal portion extending into an open end of a last one of the plurality of long legs, the thick-film resistor component defining the resistance value between the terminal portions of the first and second conductors.

These and other features of the present invention will become more apparent from the following description of the illustrative embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A–1F are cross-sectional views illustrating various processing stages of one embodiment of a low-valued, thick-film sense resistor formed on a multi-layer circuit board.

FIGS. 2A–2D are top plan views of a number of different thick film resistor configurations illustrating various embodiments of terminal connections thereto.

FIG. 3 is a top plan view of one embodiment of a thick film resistor formed in a serpentine configuration and including additional resistor material segments selectively formed to provide for incremental trimming of the resistor value.

DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS

Referring now to FIGS. 1A–1F, cross-sectional views of various processing stages of one embodiment of a low-valued, thick-film resistor component **50** formed on a multi-layer circuit board are illustrated. In the illustrated process, a thick-film material is deposited, printed, grown or otherwise formed on an electrically conductive sheet or strip **52** in a known manner such that a thick-film component **54** results having a first surface adhered to the electrically conductive sheet **52** as shown in FIG. 1A. Illustratively, the electrically conductive sheet **52** may be formed of copper (Cu), a copper compound, or other known electrically conductive material or materials. In any case, the resultant thick-film resistor **14** defines a first end **56** and an opposite second end **58**. A thick-film resistive material is deposited, printed or otherwise formed over the exposed surface of the thick-film material forming the thick-film component **54**, and in contact with the top surface of the electrically conductive sheet

5

52 about the periphery of the thick-film component **54** to form a thick-film resistor **60**. A first end **62** of the resistor **60** is in contact with, and adhered to, the sheet **52** adjacent to the first end **56** of the thick-film component **54**, and a second opposite end **64** of the resistor **60** is in contact with, and adhered to, the sheet **52** adjacent to the second end **58** of the thick-film component **54**. The thick-film resistor **60** is further adhered to all exposed surfaces of the thick-film component **54**.

As shown in FIG. 1B, an electrically insulating film **20** may optionally be deposited, printed or otherwise formed over the exposed surface of the thick-film resistor **60** and in contact with the top surface of the electrically conductive sheet **52** about the periphery of the combination thick-film component **54** and thick-film resistor **60**. If included, a first end **22** of the film **20** is in contact with, and adhered to, the sheet **52** adjacent to the first end **66** of the thick-film resistor **60**, a second opposite end **24** of the film **20** is in contact with, and adhered to, the sheet **52** adjacent to the second end **64** of the thick-film resistor **60**, and the film **20** is further adhered to all exposed surfaces of the thick-film resistor **60**.

A first electrically insulating layer **26** is formed over the combination of the thick-film resistor **60**, thick-film component **54**, electrically conductive sheet **52** and, if included, electrically insulating film **20**, as illustrated in FIG. 1B. Layer **26** is adhered to the exposed surface of the electrically conductive sheet **52** as well as to the exposed surface area of the thick-film resistor **54** (or to film **20**, in embodiments including film **20**). In one embodiment, the first electrically insulating layer **26** is a known formable flexible circuit board material, an example of which may be, but should not be limited to, FR4. Alternatively, layer **26** may be a known formable material that cures to form a rigid circuit board material, an example of which may be, but should not be limited to, an electrically non-conductive, rigidly formable epoxy.

As illustrated in FIG. 1C, a portion of the electrically conductive sheet **52** is selectively removed adjacent to the thick-film component **54** such that a portion of the first surface of the thick-film component **54** adjacent to walls **66** and **68** of the remaining portions **52C** and **52A** respectively of the sheet **52** is exposed with a section **52B** of the sheet **52** remaining therebetween. Selective removal of the portion of the sheet **52** adjacent to the thick-film component **54** as just described may be accomplished in accordance with any of a number of known techniques, examples of which may include, but should not be limited to, etching via a known chemical etchant, milling or the like. In any case, the portion **52A** of the remaining sheet **52** adjacent to wall **68** remains in contact with the thick-film component **54** adjacent end **58** and with the thick-film resistor **60** adjacent end **64** to form a first electrical contact thereto, and the portion **52C** of the remaining sheet **52** adjacent to wall **66** remains in contact with the thick-film component **54** adjacent to end **56** and with the thick-film resistor **60** adjacent end **62** to form a second electrical contact thereto, with the portion **52B** of the sheet **52** adhered to the first surface of the thick-film component **54** and a portion of the first surface of the thick-film component **54** exposed between sheet portions **52A**, **52B** and **52C** as illustrated. The value of the thick-film resistor is defined between the first and second electrical contacts.

In the illustrated embodiment, the thick-film resistor **60** is a low-valued resistor suitable for use as a sense resistor, and may typically have a resistance value of less than one ohm, although higher resistor values are contemplated. In this embodiment, the resistor material used to fabricate resistor

6

60 may have a high metallic content. In one specific embodiment, for example, resistor **60** is formed of between approximately 100–85% Silver Palladium (AgPd) and approximately 0–15% SiO₂ to form a resistor having a resistance value of a few ohms or less. In embodiments wherein the resistor material used to fabricate the thick-film resistor **60** has a sufficiently high metallic content, and wherein a chemical etchant is used to selectively remove a portion of the electrically conductive sheet **52** adjacent to the thick-film component **54** as just described, such a resistor may be reactive with this chemical etchant and therefore susceptible to etching thereby if the thick-film resistor **60** was otherwise formed directly on the surface of the electrically conductive sheet **52**. In such embodiments, the thick-film component **54** is formed between the sheet **52** and thick-film resistor **60**, as illustrated in FIGS. 1A–1F, wherein the material composition of the thick-film component is selected such that it is non-reactive with, and therefore will not be etched away by, the chemical etchant used to selectively remove portions of the electrically conductive sheet **52**, and such that it will not materially alter the resistance value of the thick-film resistor **60**. In embodiments of the thick-film resistor component **50** wherein it is desirable to selectively adjust the value of the thick-film resistor **60**, such as via resistor value adjusting radiation; e.g., a laser, the material composition of the thick-film component **54** may further be selected to allow passage therethrough of the resistor value adjusting radiation. The thick-film component **54** formed between the electrically conductive sheet **52** and the low-valued, thick-film resistor **60** as just described thus acts as a shield to isolate and protect the thick-film resistor **60** from the chemical etchant used to selectively remove portions of the electrically conductive sheet **52**.

In one embodiment, the material forming the thick-film component **54** may be an electrically insulating material, such as SiO₂, Si₃N₄, polyimide or other electrically insulating material that may be deposited, printed, grown or otherwise formed on the sheet **52** in a known manner, and that is non-reactive with the chemical etchant used to selectively remove portions of the electrically conductive sheet **52**. In this embodiment, the electrically insulating material forming the thick-film component **54** will generally not affect the resistance value of the thick-film resistor **60**, and any such electrically insulating material may be selectively removed via resistor value adjusting radiation in the adjustment of the thick-film resistor **60** without adversely affecting the structure and operation of the thick-film resistor component **50**.

In an alternate embodiment, the thick-film material forming the thick-film component **54** may be another resistive material such as a polymer-based resistive material or other known resistive material having a sufficiently low metallic content such that it is non-reactive with the chemical etchant used to selectively remove portions of the electrically conductive sheet **52**. In this case, the thick-film component **54** will thus be a second thick-film resistor having one end **64** in electrical contact with the first electrical contact formed by remaining portion **52A** of the electrically conductive sheet **52**, an opposite end **62** in electrical contact with the second electrical contact formed by remaining portion **52C** of the electrically conductive sheet, and a top surface adhered and electrically bonded to the bottom surface of the thick-film resistor **60**, such that the resulting thick-film resistor component **50** is the parallel combination of resistors **54** and **60**. To avoid materially affecting the resistance value of the thick-film resistor **60** in this embodiment, it is desirable to select or configure the resistive material used to

form the second thick-film resistor **54** such that the resistance value of the second thick-film resistor **54** is substantially greater than the resistance value of the first thick-film resistor **60**. In this embodiment, resistive material from the second thick-film resistor **54** may be selectively removed via

resistor value adjusting radiation in the adjustment of the thick-film resistor **60** without adversely affecting the structure and operation of the thick-film resistor component **50**. In either of the foregoing illustrative examples, the value of the thick-film resistor **60** may be adjusted by selectively removing one or more portions of the resistor material used to form resistor **60** in a known manner. As further illustrated in FIG. **1C**, for example, a pair of radiation-producing apparatus **32A** and **32B**; e.g., lasers, may be configured to controllably direct resistor value adjusting radiation **34A** and/or **34B** through thick-film component **54** to one or more selected portions of the thick-film resistor **60** to selectively remove resistor material therefrom in a known manner and thereby controllably adjust the value of the resistor **60**.

A second electrically insulating layer **36** may be formed over the exposed first side of the thick-film component **54** and the exposed underside of the electrically conductive sheet portions **52A**, **52B** and **52C** as illustrated in FIG. **1D**, and a second electrically conductive sheet **38** may be formed over the second electrically insulating layer **36**. Other circuit-carrying and/or electrically insulating layers may further be added to the thick-film resistor component **50** illustrated in FIGS. **1A–1D** to complete a circuit or subcircuit as is known in the art. In any case, layer **36** is adhered to the exposed first surface of the thick-film component **50** and to the exposed underside of the electrically conductive sheet **52**. In one embodiment, the second electrically insulating layer **36** is identical to the first electrically insulating layer **26**, and is a known formable flexible circuit board material, an example of which may be, but should not be limited to, FR4. Alternatively, layer **36** may be a known formable material that cures to form a rigid circuit board material, an example of which may be, but should not be limited to, an electrically non-conductive, rigidly formable epoxy.

In the embodiment illustrated in FIGS. **1B–1F**, the material composition of the electrically insulating film **20**, if included, may be selected to accomplish any one or combination of a number of functions. For example, it may be desirable, depending upon the material compositions of the thick-film resistor **60**, thick film component **50** and/or first electrically insulating layer **26**, to select the material composition of the film **20** such that it promotes adhesion between resistor **14** and layer **26**. Such a film **20** may be formed of a polymer and ceramic bead combination developed by E.I. DuPont De Nemurs & Co., and has been found to provide such adhesion promoting properties. Those skilled in the art will recognize other adhesion promoting compositions suitable for use in forming film **20**, and that such other compositions will generally be determined, at least in part, by the material compositions of the thick-film resistor **60**, thick-film component **50**, and/or the first electrically insulating material **26**, and possibly by the fabrication environment and/or operating environment of the resulting product. Any such other adhesion promoting compositions of the electrically insulating film **20** are intended to fall within the scope of the claims appended hereto.

It may further be desirable, again depending upon the material compositions of the thick-film resistor **60**, thick-film component **50** and/or the first electrically insulating layer **26**, to select the material composition of the film **20**

such that it supports, and provides stress relief to, the resistor **60**. For example, in embodiments wherein the thick-film resistor **60**, thick-film component **50** and first electrically insulating layer **26** are flexible components, it may be desirable to formulate film **20** such that it supports, and provides stress relief to, the resistor **60**. Again, one formulation of film **20** that provides such support and stress relief is a polymer and ceramic bead combination developed by E.I. DuPont De Nemurs & Co. as described hereinabove. Those skilled in the art will recognize other compositions suitable for use in forming film **20** that provides support to, and stress relief to, the thick-film resistor **60**, and that such other compositions will generally be determined, at least in part, by the material compositions of the thick-film resistor **60**, thick-film component **50** and/or the first electrically insulating material **26**, and possibly by the fabrication environment and/or operating environment of the resulting product. Any such other compositions of the electrically insulating film **20** are intended to fall within the scope of the claims appended hereto.

In embodiments wherein the value of the thick-film resistor **60** is adjusted or “trimmed” via resistor value adjusting radiation; e.g., a laser, it may further be desirable to select the material composition of the film **20** such that it diverts or absorbs any of the radiation that passes through the resistor **60** in the direction of the first electrically insulating layer **26**, as well as any resulting heat generated thereby. Damage to the first electrically insulating layer **26** and any circuitry contained therein can thereby be avoided. For purposes of this description, the term “radiation blocking” will be used hereinafter to describe the property of the electrically insulating film **20** that allows it to divert or absorb radiation produced by radiation sources **32A** and **32B** and any heat generated thereby, and to accordingly inhibit passage of radiation and heat through the film **20** into the first electrically insulating layer. Again, one formulation of film **20** that provides such radiation blocking is a polymer and ceramic bead combination developed by E.I. DuPont De Nemurs & Co. as described hereinabove. Those skilled in the art will recognize other compositions suitable for use in forming film **20** that provides such a radiation blocking feature, and that such other compositions will generally be determined, at least in part, by the material compositions of the thick-film resistor **60**, thick-film component **50** and/or the first electrically insulating material **26**, as well as the strength and wavelength of the radiation **34A** and **34B** produced by the radiation sources **32A** and **32B** respectively. Any such other compositions of the electrically insulating film **20** are intended to fall within the scope of the claims appended hereto.

In some applications, resistor component **50** may be required to dissipate a substantial amount of power, thereby resulting in the generation of heat. It may accordingly be desirable to provide resistor component **50** with a heat sink structure to dissipate heat generated by the resistor component **50**, and a process for fabricating one embodiment of such a heat sink structure is illustrated in FIGS. **1E–1F**. Referring to FIG. **1E**, a number of portions of the second electrically conductive sheet **38** and corresponding underlying portions of the second electrically insulating layer **36** are removed to form wells, bores or vias **74A–74E** extending to the third remaining portion **52B** of the first electrically conductive sheet **52B**. Wells, bores or vias **74A–74E** may be formed via conventional techniques including for example, but not limited to, chemical etching, micro-machining, etc. A number of walled portions of the second electrically insulating layer **36** are defined thereby; e.g., four such

walled portions shown in FIG. 1E, which are capped by remaining portions 38C–38F of the second electrically conductive sheet 38. To isolate the heat sink structure from the remaining portions of the second electrically conductive sheet 38, portions of the second electrically conductive sheet 38 are removed adjacent to wells 74A and 74E respectively, resulting in a first portion 38A, terminating at wall 72, and a second portion 38H, terminating at wall 70, and two cap portions 38B and 38G adjacent to wells 74A and 74E respectively.

Referring to FIG. 1F, thermally conductive members are formed within each of the wells, bores or vias 74A–74E in thermal contact with the third portion of the first electrically conductive sheet 52B. The thermally conductive members may be formed via conventional techniques, and may be the same material used to form the electrically conductive sheets 52 and 38, although other known thermally conductive materials may alternatively be used to form the thermally conductive members. In any case, a thermally conductive sheet 78 is then formed over and in thermal contact with the thermally conductive members, wherein the thermally conductive sheet 78 terminates at walls 80 and 82 respectively, adjacent to but spaced apart from walls 70 and 72 of the second portion 38H and first portion 38A respectively of the second electrically conductive sheet 38. In the illustrated embodiment, the thermally conductive sheet 78 is formed of the same material used to form the second electrically conductive sheet 38, and the thermally conductive sheet 78 accordingly appears in FIG. 1F as a unitary structure. Alternatively, other known thermally conductive materials may be used to form the thermally conductive sheet 78, wherein such other thermally conductive materials may adhere to, or bond with, the portions 38B–38G of the second electrically conductive sheet 38, or alternatively still, the portions 38B–38G may be removed prior to forming the thermally conductive sheet 78. In any case, the thermally conductive sheet 78 is in thermal contact with the third portion 52B of the first electrically conductive sheet 52 via the thermally conductive members formed therebetween, to thereby provide a heat sink structure operable to draw heat away from the thick-film resistor component 50.

Referring now to FIGS. 2A–2D, top plan views are shown of a number of different thick film resistor configurations illustrating various embodiments of terminal connections thereto. In FIG. 2A, for example, one embodiment of a thick-film resistor 100 includes a resistor pattern 102 formed from a known resistor material on a substrate in a rectangular configuration using known techniques therefore. Resistor pattern 102 defines a first edge 104, a second edge 106 opposite and parallel to the first edge 104 and generally parallel edges extending therebetween. A first electrical conductor 108 has a first portion 108A extending to the resistor pattern 102 and a second terminal portion 108B extending into the resistor along one of the edges parallel to edge 104 and terminating at an opposite edge parallel to edge 104. Similarly, a second electrical conductor 110 has a first portion 110A extending to the resistor pattern 102 and a second terminal portion 110B extending into the resistor along one of the edges parallel to edge 106 and terminating at an opposite edge parallel to edge 106. Terminal portions 108B and 110B extend into the same edge of the resistor pattern 102, and angle generally toward each other and away from their respective edges 104 and 106, and define the value of the resistor 100 therebetween. Alternatively, the terminal portions 108A and 108B may extend beyond opposite edge parallel to edges 104 and 106. In any case, the thick-film resistor 100 may be adjusted or “trimmed” in

value via known techniques. An example of one such technique is via resistor value adjusting radiation; e.g., laser trimming, and radiation from a suitable resistor value adjusting radiation source (not shown) may be directed to the resistor pattern 102 in, for example, the direction and location indicated by arrow 112. By way of illustration only, example dimensions of the resistor 100 illustrated in FIG. 2A may be: resistor pattern 102=30×50 mils, terminals 108 and 110=5 mils wide, and spacing between the top portions of the terminals 108 and 110 and corresponding resistor pattern sides 104 and 106=7 mils. It will be understood, however, that such dimensions may differ depending upon the application, and any such alternate dimensions are intended to fall within the scope of the claims appended hereto.

Another example embodiment of a thick-film resistor 120 is illustrated in FIG. 2B, and includes a resistor pattern 122 formed from a known resistor material on a substrate in a generally rectangular configuration using known techniques therefore. Resistor pattern 122 defines a pair of parallel notches or channels 124 and 126 each extending into one edge 130 of the resistor pattern and terminating within the resistor pattern 122 at channel ends 124A and 126A respectively. Edge 130 extends away from channel 126 and beyond channel 124 to a first edge 128, and likewise extends away from channel 124 and beyond channel 126 to a second edge 132 opposite edge 126. A fourth edge, opposite edge 130, extends between edges 128 and 132 generally parallel with edge 130, and defines a v-shaped notch “N” positioned between channels 124 and 126. A first electrical conductor 134 has a first portion 134A extending to edge 130 between edge 128 and channel 124, and a second terminal portion 134B extending into the resistor pattern 122 in a direction generally parallel with edge 128. Similarly, a second electrical conductor 136 has a first portion 136A extending to edge 130 between edge 132 and channel 126, and a second terminal portion 136B extending into the resistor pattern 122 in a direction generally parallel with edge 132. Terminal portions 134B and 136B define a resistive path and a resistor value therebetween that is routed generally around the terminal ends 124A and 126A of channels 124 and 126 respectively. The thick-film resistor 120 may be adjusted or “trimmed” in value via known techniques. An example of one such technique is via resistor value adjusting radiation; e.g., laser trimming, and radiation from a suitable resistor value adjusting radiation source (not shown) may be directed to the resistor pattern 122, for example, into the v-shaped notch “N” in the direction indicated by arrow 138. By way of illustration only, example dimensions of the resistor 120 illustrated in FIG. 2B may be: resistor pattern 122=70×85 mils, channels 124 and 126=10.5×58 mils, notch N=10 mils wide at open end×5 mils deep and terminals 134 and 136=5 mils wide and 12 mils deep into the resistor pattern 122. It will be understood, however, that such dimensions may differ depending upon the application, and any such alternate dimensions are intended to fall within the scope of the claims appended hereto.

A further example embodiment of a thick-film resistor 140 is illustrated in FIG. 2C, and includes a resistor pattern 142 formed from a known resistor material on a substrate in a generally rectangular configuration using known techniques therefore. Resistor pattern 142 defines a channel or notched-out portion 144 extending into one edge of the resistor pattern 142 and terminating within the resistor pattern 142 at generally parallel channel ends 146 and 150 respectively. One edge 148 of the resistor pattern 142 is generally parallel with edges 146 and 160, and a second

edge **152** opposite edge **148** is generally parallel with edges **146**, **148** and **150**. A fourth edge, opposite the terminal end of channel **144**, extends between edges **148** and **152**. A first electrical conductor **154** has a first portion **154A** extending to the resistor pattern **142** between edges **146** and **148**, and a second terminal portion **154B** extending into the resistor pattern **142** in a direction generally parallel with edges **146** and **148**. Similarly, a second electrical conductor **156** has a first portion **156A** extending to the resistor pattern **142** between edges **150** and **152**, and a second terminal portion **156B** extending into the resistor pattern **142** in a direction generally parallel with edges **150** and **152**. Terminal portions **154B** and **156B** define a resistive path and a resistor value therebetween that is routed generally around the channel **144**. The thick-film resistor **140** may be adjusted or “trimmed” in value via known techniques. An example of one such technique is via resistor value adjusting radiation; e.g., laser trimming, and radiation from a suitable resistor value adjusting radiation source (not shown) may be directed to the resistor pattern **142** in, for example, the direction and location indicated by arrow **158**. By way of illustration only, example dimensions of the resistor **140** illustrated in FIG. 2C may be: resistor pattern **142**=50×50 mils, channel **144**=20×30 mils and terminals **154** and **156**=5 mils wide and 10 mils deep into the resistor pattern **142**. It will be understood, however, that such dimensions may differ depending upon the application, and any such alternate dimensions are intended to fall within the scope of the claims appended hereto.

Yet another example embodiment of a thick-film resistor **160** is illustrated in FIG. 2D, and includes a resistor pattern formed from a known resistor material on a substrate in a generally rectangular configuration using known techniques therefore. The resistor pattern defines a first edge **162**, a second edge **164** opposite the first edge **162**, and a pair of opposing and generally parallel edges **166** and **168** extending edges **162** and **164**. Edge **166** defines a v-shaped notch “N” positioned approximately equidistant from edges **162** and **164**. A first electrical conductor **180** has a first terminal portion **182** extending to the resistor pattern along edge **164**, and a second terminal portion **184** exiting the resistive material along edge **168**. Similarly, a second electrical conductor **186** has a first terminal portion **188** extending to the resistor pattern along edge **162**, and a second terminal portion **190** exiting the resistive material along edge **166**. The electrical conductor **180** forms a right angle between terminal portions **182** and **184**, and the electrical conductor **186** forms a right angle between terminal portions **188** and **190**, although it will be understood that terminal portions **182** and **184**, and/or terminal portions **188** and **190**, may alternatively be formed at other angles or curvatures relative to each other. The terminal portions of electrical conductors **180** and **186** define a resistive path and a resistor value therebetween generally along the direction of arrows **192** and **194**. The thick-film resistor **160** may be adjusted or “trimmed” in value via known techniques. An example of one such technique is via resistor value adjusting radiation; e.g., laser trimming, and radiation from a suitable resistor value adjusting radiation source (not shown) may be directed to the resistor pattern, for example, into the v-shaped notch “N” in the direction indicated by arrow **170**. By way of illustration only, example dimensions of the resistor **160** illustrated in FIG. 2D may be: resistor pattern **162**=30×40 mils, notch N=10 mils wide at open end×5 mils deep and terminals **184** and **166**=5 mils wide. It will be understood, however, that such dimensions may differ

depending upon the application, and any such alternate dimensions are intended to fall within the scope of the claims appended hereto.

Depending upon the material compositions of the resistive material used to form any of the thick-film resistors **100**, **120**, **140** and **160** and of the electrically conductive material used to form the electrical conductors thereto, differences in the coefficient of thermal expansion (CTE) of the two materials may result in undesirable stress therebetween. Such stress may occur, for example, in embodiments wherein the thick-film resistors **100**, **120**, **140** and **160** are formed of a ceramic-based resistive material and the corresponding electrical conductors are formed of copper (Cu), Aluminum (Al), and/or alloys thereof. Those skilled in the art will recognize other resistive material and electrical conductor composition combinations resulting in undesirable stress therebetween resulting from mismatches in CTEs. In such cases, it is desirable to size the terminal portions of the electrical conductors so as to minimize stress resulting from a mismatch between the coefficient of thermal expansion of the thick-film resistor material and the coefficient of thermal expansion of the terminal portions of the electrical conductors. Generally, such sizing of the terminal portions of the electrical conductors may be accomplished by minimizing the lengths and/or widths, where appropriate and where possible, to minimize the total surface areas defining the interfaces between the electrical conductors and the resistor patterns. Those skilled in the art will recognize, however, that the minimum lengths and/or widths of the terminal portions of the electrical conductors will generally be limited by a number of factors including, but not necessarily limited to, the current dissipation requirements of the resistor, the desired value of the resistor, and the like.

It may further be desirable with the thick-film resistor embodiments illustrated in FIGS. 2A–2D to configure the terminal portions of the electrical conductors such that, with a simple or relatively simple resistor pattern, a wide range of resistor values are possible simply by adjusting the positions of the electrical conductors and/or terminal portions thereof relative to the resistor patterns. For example, with the thick-film resistor embodiment **160** illustrated in FIG. 2D, the generally “L” shaped electrical conductors **180** and **186** allow for adjustment of their positions relative to the resistor pattern and to each other, as indicated by directional arrows **192** and **194**, to provide for a wide range of resistor values using the simple rectangular resistor pattern illustrated in FIG. 2D. By moving the position of the electrical conductor **180** relative to the resistor pattern defining resistor **160** either toward or away from the electrical conductor **186** in the direction indicated by arrow **192**, and/or by moving the position of the electrical conductor **186** relative to the resistor pattern defining resistor **160** either toward or away from the electrical conductor **180** in the direction indicated by arrow **194**, many different resistor values are possible without altering the simple, rectangular shape of the resistor pattern. Likewise, by moving the position of the terminal portion **108A** of the electrical conductor **108** relative to the resistor pattern **102** defining resistor **100** of FIG. 2D either toward or away from the terminal portion **110A** of the electrical conductor **110**, and/or by moving the position of the terminal portion **110A** of the electrical conductor **110** relative to the resistor pattern **102** defining resistor **100** either toward or away from the terminal portion **108A** of the electrical conductor **108**, many different resistor values are possible without altering the simple, rectangular shape of the resistor pattern **102**. With slightly more complicated resistor patterns, such as those illustrated in FIGS. 2B and 2C,

positioning of the terminal portions of the electrical conductors **134**, **136**, **154** and **156** relative to each other and/or relative to the corresponding resistor patterns **122** and **142** respectively, allows for some adjustment in the corresponding resistor values, albeit less of an adjustment available with simpler resistor patterns such as those illustrated in FIGS. **2A** and **2D**.

Referring now to FIG. **3**, a top plan view of an illustrative embodiment **200** of a thick film resistor is shown formed in a serpentine configuration and including additional resistor material segments selectively formed to provide for incremental adjustment of the resistor value. Thick-film resistor **200** is formed on a substrate from a thick-film resistor material **202** of known material composition in a serpentine configuration with a plurality of long legs having long edges positioned adjacent to each other and a plurality of short legs connecting alternate ends of the plurality of long legs such that resulting adjacent pairs of the long legs each have a closed end and an open end. In the illustrated embodiment, for example, resistor **200** includes 10 long legs **204A–204J** positioned substantially parallel with each other, although those skilled in the art will recognize that one or more of the long legs **204A–204J** need not be parallel, but may instead be merely positioned adjacent to neighboring long legs in any desired configuration. Five short legs, **206A–206E**, connect the ends of pairs of adjacent long legs, e.g., short leg **206A** connects the ends of adjacent long legs **204A** and **204B**, etc., such that these adjacent pairs of long legs have closed ends, e.g., where the short legs **206A–206E** are formed, and opposite open ends, e.g., the ends of the long legs opposite the short legs **206A–206E**. Four additional short legs, **208A–208D**, connect alternate pairs of adjacent long legs, e.g., short leg **208A** connects the ends of adjacent long legs **204B** and **204C**, etc., such that these alternate adjacent pairs of long legs have closed ends, e.g., where the short legs **208A–208E** are formed, and opposite open ends, e.g., the ends of the long legs opposite the short legs **208A–208E**.

In the illustrated embodiment, the terminal portion of a first electrical conductor **210A** extends into the open end **208E** of a first one of the long legs **204A** to form a first electrical contact or terminal of resistor **200**. Likewise, the terminal portion of a second electrical conductor **210B** extends into the open end **208F** of a last one of the long legs **204J** to form a second electrical contact or terminal of resistor **200**, such that the resistor **200** defines a resistor value between the terminal portions of the first and second electrical conductors **210A** and **210B**. Those skilled in the art will recognize that either of the resistor terminals may alternatively be defined at open or closed ends of any of the long legs **204A–204J**, or at any of the short legs **206A–206E** or **208A–208D**, and any such alternate positioning of either of the resistor terminals is intended to fall within the scope of the claims appended hereto.

The thick-film resistor **200** further includes number of first resistor segments connecting open ends of one or more adjacent pairs of the long resistor legs. In the illustrated example, five such resistor segments **212A–212E** are arranged to each connect the open ends of adjacent long leg pairs **204A–204B**, **204C–204D**, **204E–204F**, **204G–204H** and **204I–204J**. It will be understood that the number of the first resistor segments included with resistor **200** may vary between one and as many open ends are defined by adjacent pairs of long resistor legs. It will further be understood that although the number of first resistor segments are illustrated in FIG. **3** as all being arranged on one side of the thick-film resistor **200**, one or more of the first resistor segments may

alternatively or additionally be formed on the opposite side of the resistor **200**, e.g., to connect open ends of any one or more of the adjacent pairs of long legs **204B–204C**, **204D–204E**, **204F–204G** and **204H–204I**.

Any of the number of first resistor segments **212A–212E** defines a resistance path therethrough that is less than any of the adjacent pairs of long legs. Consequently, any of the adjacent pairs of long resistor legs having an open end connected by one of the first resistor segments **212A–212E** defines a smaller resistance than would otherwise be the case in the absence of the first resistor segment. In the embodiment illustrated in FIG. **3**, for example, the value of the thick-film resistor **200** is initially defined through segments **212A–212E**, which may be a substantially smaller resistance value than the value of the resistor **200** that would be defined through legs **204A–204J** and **206A–206E** in the absence of segments **212A–212E**. Each of the number of first resistor segment, e.g., **212A–212E**, is configured to be selectively open-circuited to incrementally adjust the resistance value of the resistor **200**. Any known technique may be use for open circuiting one or more of the first number of thick-film resistor segments, e.g., **212A–212E**, and in one embodiment resistor value adjusting radiation controllably applied via a resistor value adjusting radiation source, e.g., a laser, is used to cut through a portion of selected ones of the first number of resistor segments **212A–212E** to thereby incrementally adjust the resistance value of the resistor **200**.

In the illustrated embodiment, each of the number of first resistor segments **212A–212E** has a long segment **214A–214E**, positioned generally parallel with a corresponding short leg **206A–206E**, connected at each end to a corresponding one of the adjacent long leg pairs via short segments **216A–216E** and **218A–218E**, wherein each of the short segments **216A–216E** and **218A–218E** are arranged generally perpendicularly to their corresponding long segments **214A–214E** and generally parallel with their corresponding adjacent long leg pairs. In this embodiment, either of the short segments **216A–216E** or **218A–218E**, or the long segments **214A–214E**, may be open-circuited via a known thick-film resistor open-circuiting technique. For example, in the embodiment illustrated in FIG. **3**, the short segment **218E** of resistor segment **212E** is shown as being open-circuited via laser radiation directed through path **C1** in the direction of arrow **220**. As a result, current flowing from short leg **208D** to terminal **210B**, or vice-versa, must then flow through legs **204I**, **206E** and **204J**, and the resistance value of the resistor **200** is thereby incrementally increased. In any case, it will be understood that any one or more of the number of first resistor segments **212A–212E** may be arranged in any desired shape as long as each connect an open end of an appropriate pair of adjacent long legs **204A–204J**, and as long as each may be open-circuited via a known thick-film resistor open-circuiting technique.

Resistor **200** may further include a number of second resistor segments connecting adjacent pairs of long resistor legs **204A–204E** somewhere along their long edges between open and closed ends thereof. In the illustrated example, two such resistor segments **222A** and **212B** are connected between adjacent long legs **204I** and **204J** to divide each of the long legs **204I** and **204J** into three possible resistance values. In the absence of resistor segment **212E**, if resistor segment **222A** is intact, then the resistance value from terminal **210B** and short leg **208D** is defined through leg **204J**, segment **222A** and leg **204I**. If, however, resistor segment **222A** has been selectively open circuited, such as via laser radiation directed through path **C2** in the direction of arrow **224**, the resistance value from terminal **210B** and

15

short leg 208D is defined through leg 204J, segment 222B and leg 204I. Finally, if both of the resistor segments 222A and 222B have been selectively open-circuited, the resistance value from terminal 210 and short leg 208D is defined through leg 204J, leg 206E and leg 204I. Those skilled in the art will recognize that any number of the second resistor segments may be arranged between any one or more of the pairs of adjacent long resistor legs, wherein each of the number of second resistor segments is configured to be open-circuited via a known thick-film resistor opening technique. For example, one such resistor segment 226 is shown in FIG. 3 as connected between adjacent long resistor legs 204H and 204I, wherein segment 226 may be open-circuited, such as via resistor value adjusting radiation directed along the path indicated by arrow 228, to provide for up to two different resistance values between resistor legs 206D and 206E. As another example, four such resistor segments 230A–230D are illustrated in FIG. 3 as connected between adjacent long legs 204G and 204H, wherein any one or more of the resistor segments 230A–230D may be selectively open-circuited, such as via resistor value adjusting radiation directed along the path indicated by arrow 232, to provide for up to five different resistor values between resistor legs 208D and 208C. It will be understood that although each of the resistor segments 222A–222B, 226 and 230A–230D are illustrated in FIG. 3 as being arranged generally perpendicularly to their corresponding long leg pairs and generally parallel with their corresponding short legs, any one or more of the number of second resistor segments 222A–222B, 226 or 230A–230D may be arranged in any desired shape as long as each connects together an adjacent pair of long legs between its open and closed ends, and as long as each may be open-circuited via a known thick-film resistor open-circuiting technique.

While the invention has been illustrated and described in detail in the foregoing drawings and description, the same is to be considered as illustrative and not restrictive in character, it being understood that only illustrative embodiments thereof have been shown and described and that all changes and modifications that come within the spirit of the invention are desired to be protected.

The invention claimed is:

1. A thick-film resistor component, comprising:

a first electrically conductive sheet having first and second opposite surfaces;

a first thick-film component having first and second opposite surfaces, the first surface of the first thick-film component adhered to the first surface of the first sheet;

a first thick-film resistor having first and second surfaces, the first surface of the first resistor adhered to the second surface of the first thick-film component and to the first surface of the first sheet adjacent to the first thick-film component; and

a first electrically insulating layer formed over the combination of the first thick-film component and the first resistor and the first electrically conductive sheet;

wherein a portion of the first sheet is selectively removed adjacent to the first thick-film component such that a remaining first portion of the first sheet defines a first electrical contact to the first resistor, a remaining second portion of the first sheet defines a second electrical contact to the first resistor, and the first surface of the first thick-film component is at least partially exposed therebetween, the first resistor forming the thick-film resistor component between the first and second contacts

16

wherein the portion of the first electrically conductive sheet is selectively removed via an etchant; and wherein the first thick-film component is formed of a material that is unreactive with the etchant and the first thick-film resistor is formed of a material that is reactive with the etchant, the first thick-film component shielding the first thick-film resistor from the etchant.

2. The resistor component of claim 1 wherein the first thick-film component is formed of an electrically insulating material.

3. The resistor component of claim 2 wherein the electrically insulating material forming the first thick-film component is silicon dioxide.

4. The resistor component of claim 1 wherein the first thick-film component is a second thick-film resistor;

and wherein the second surface of the second thick-film resistor is electrically bonded to the first surface of the first resistor;

and wherein the first and second contacts are each in electrical contact with both of the first and second thick-film resistors, the first and second thick-film resistors defining a parallel-connected thick-film resistor component.

5. The resistor component of claim 4 wherein the material forming the first thick-film resistor has a higher metal content than the material forming the second thick-film resistor.

6. The resistor component of claim 4 wherein the first thick-film resistor is a low-valued sense resistor and the second thick-film resistor has a resistor value substantially higher than the low-valued sense resistor.

7. The resistor component of claim 4 wherein the first thick-film resistor is formed of a combination of a metallic compound and an electrically insulating material and the second thick-film resistor is formed of a polymer-based resistor film.

8. The resistor component of claim 1 further including an electrically insulating film formed over the second surface of the first thick-film resistor and in contact with the first surface of the first sheet about a periphery of the combination of the first thick-film component and first thick-film resistor;

and wherein the first electrically insulating layer is formed over and in contact with the electrically insulating film and the first surface of the first electrically conductive sheet, the electrically insulating film configured to bond to both the second surface of the first thick-film resistor and the first electrically insulating layer.

9. The resistor component of claim 8 wherein the first insulating layer is a flexible insulating layer.

10. The resistor component of claim 9 wherein the electrically insulating film is configured to support the combination of the first thick-film component and the first thick-film resistor, and provide stress relief to the combination of the first thick-film component and the first thick-film resistor, between the first and second electrical contacts.

11. The resistor component of claim 10 wherein the electrically insulating film is formed as a combination of a polymer and ceramic.

12. The resistor component of claim 1 further including a second electrically insulating layer formed over the second surface of the first sheet and in contact with the at least partially exposed first surface of the first thick-film component.

13. The resistor component of claim 12 wherein the second insulating layer is a flexible insulating layer.

17

14. The resistor component of claim **12** further including a second electrically conductive sheet formed over the second electrically insulating layer.

15. The resistor component of claim **14** further including:
a number of thermally conductive members extending 5
through the second electrically insulating layer in contact with a remaining third portion of the first electrically conductive sheet in contact with the first thick-film component and positioned between the first and second electrical contacts; and

18

a thermally conductive sheet formed on the second electrically insulating layer in electrical contact with the number of thermally conductive members and electrically isolated from the second electrically conductive layer, the third portion of the first electrically conductive sheet, the number of thermally conductive members and the thermally conductive sheet forming a heat sink for the thick-film resistor component.

* * * * *